—研究ノート—
Scientific Note

Detection Capability of Earthquakes Recorded at Syowa Station, Antarctica, from 1987 to 1993

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南極・昭和基地における地震検知率

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要旨：昭和基地 (69.0° S, 39.6° E) では，1967 年より短周期，長周期各 3 成分のアナログ記録による地震記象の読み取り作業が開始された．越冬の地球物理定常隊員により観測の保守がなされ，着震時の読み取り作業が現在まで継続して行われている．験震した走時と震源のデータは，アメリカ地質調査所 (USGS) と国際地震センター (ISC) に定期的に送られると共に，極地研究所で再験震を行い "JARE Data Reports (Seismology)" として発刊されている．近年，エレクトロニクス技術の進歩によりモニター記録の質が向上すると共に，同一の基準で再験震がなされた．本稿では，1987 年より 1993 年の 7 年間における験震データを用いて，昭和基地で記録される地震の空間分布と時間的推移を詳しく調べ，また ISC データを用いた結果と比較することで昭和基地の地震検知率について考察した．

Abstract: Phase readings of teleseismic earthquakes at Syowa Station (69.0° S, 39.6° E), Antarctica have been carried out since 1967 by use of analog records of three-component short- and long-period seismometers. Seismic observations and phase readings have been conducted by the wintering members for geophysics of the Japanese Antarctic Research Expedition (JARE). The arrival times of *P*-waves have been reported to the United States Geological Survey (USGS) and the International Seismological Center (ISC), then published as the "JARE Data Reports (Seismology)" by the National Institute of Polar Research (NIPR). In recent years, the quality of chart records has been improved by the advance of electronics. In this paper, the hypocentral distribution of the detected earthquakes for the seven year period from 1987 to 1993 was presented and the spatial distribution and time variations for epicental parameters were investigated. Moreover, the detection capability of earthquakes was discussed in relation to the report from ISC data.

1. Introduction

Seismic observations at Syowa Station, Antarctica were started by using a vertical-component short-period seismometer at the foot of the western hill on which the main buildings are located in 1959 (ETO, 1962). Phase readings for teleseismic events have been carried out since 1967 by use of analog records of the three-

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component short- and long-period seismometers with 1.0 s and 15.0 s natural periods, respectively (KAMINUMA *et al*., 1968). A new seismographic vault was constructed in 1970 (69°00′31.7″ S, 39°35′31.6″ E, 20 m above mean sea level) and the observations have been continued in the vault (KAMINUMA and CHIBA, 1973). A three-component broad-band seismometer with a flat frequency response from 0.1 s to 360 s was installed in April 1989, and observations were started along with the above two seismometers (MURAKAMI and KAMINUMA, 1991). The digital velocity output signal has been recorded since May 1990 (NAGASAKA *et al*., 1992). The recent observation system and problems with it are described by KANAO and KAMINUMA (1993).

Seismic observations and phase readings for teleseismic earthquakes have been carried out by the geophysics wintering members of every JARE party. The arrival times of seismic phases have been reported to the United States Geological Survey (USGS) and the International Seismological Center (ISC) by making use of tele-fax or e-mail. After finishing the observation period for the wintering party, the events identified as teleseismic earthquakes were re-scaled in the National Institute of Polar Research (NIPR) by referring to the epicenters that were reported as the Preliminary Determination of Epicenters (PDE) by the National Earthquake Information Center (NEIC). All epicentral data and re-scaled arrival times were compiled and published as the "JARE Data Reports, Seismological bulletin of Syowa Station, Antarctica" for every year.

In the last few years, the quality of monitor records has been improved by the advance of electronics technology. Earthquakes have been detected with exact accuracy of time reading from 1987 to 1993 (AKAMATSU and KAMINUMA, 1989; KAMINUMA and ICHIKAWA, 1990; KAMINUMA and MURAKAMI, 1991; KAMINUMA and NAGASAKA, 1992; KAMINUMA and YAMAMOTO, 1993; KANAO, 1994; OKANO and KANAO, 1995). From 1987 to 1990, particularly, critical re-scaling was done; the modified arrival times and epicenters are listed by KANAO (1995).

The main purpose of this paper is to evaluate the detection of teleseismic earthquakes at Syowa Station. The epicental distributions from 1987 to 1993 are presented and time variations and magnitude dependency of epicental parameters are investigated. Moreover, the detection capability of earthquakes is discussed in relation to the ISC data and previous studies in the southern hemisphere.

2. Phase Determination and Earthquake Selection

The phase determination procedures conducted in NIPR are described as follows. An initial phase of each event was scaled carefully on the seismograms recorded by the analog chart-monitor on the basis of the arrival time estimated from the PDE hypocentral data. Paper speed of chart-monitors was 4 mm/s for the short-period seismograms. The onsets of teleseismic events were identified within the accuracy of 3.0 s, and arrival times of initial phases as well as several other predominant phases such as PKP phases were determined. Most phases were scaled on the vertical-component seismogram; only clear phases were determined on the horizontal components. Time accuracy of the arrival time data was estimated to be ± 0.2 s, which was caused by read-out errors in identification of the arrival time.

The numbers of detected earthquakes for each year from 1987 to 1993 are listed in Table 1. The numbers detected in each year ranges from 400 to 800; the total number for the seven years was 4302, with an average of about 600 events per year. The epicentral distributions for the seven years are shown in Figs. 1a-1b with two different projections. The sizes of open circles which show the epicenters is propor-

Table 1. Number of detected earthquakes at Syowa Station in the seven-year period from 1987 to 1993. The corresponding JARE parties are shown on the right-hand side.

Year	Number	JARE party
1987	393	JARE-27 (January), JARE-28 (February-December)
1988	489	JARE-28 (January), JARE-29 (February-December)
1989	788	JARE-29 (January), JARE-30 (February-December)
1990	820	JARE-30 (January), JARE-31 (February-December)
1991	409	JARE-31 (January), JARE-32 (February-December)
1992	614	JARE-32 (January), JARE-33 (February-December)
1993	789	JARE-33 (January), JARE-34 (February-December)
Total	4302	

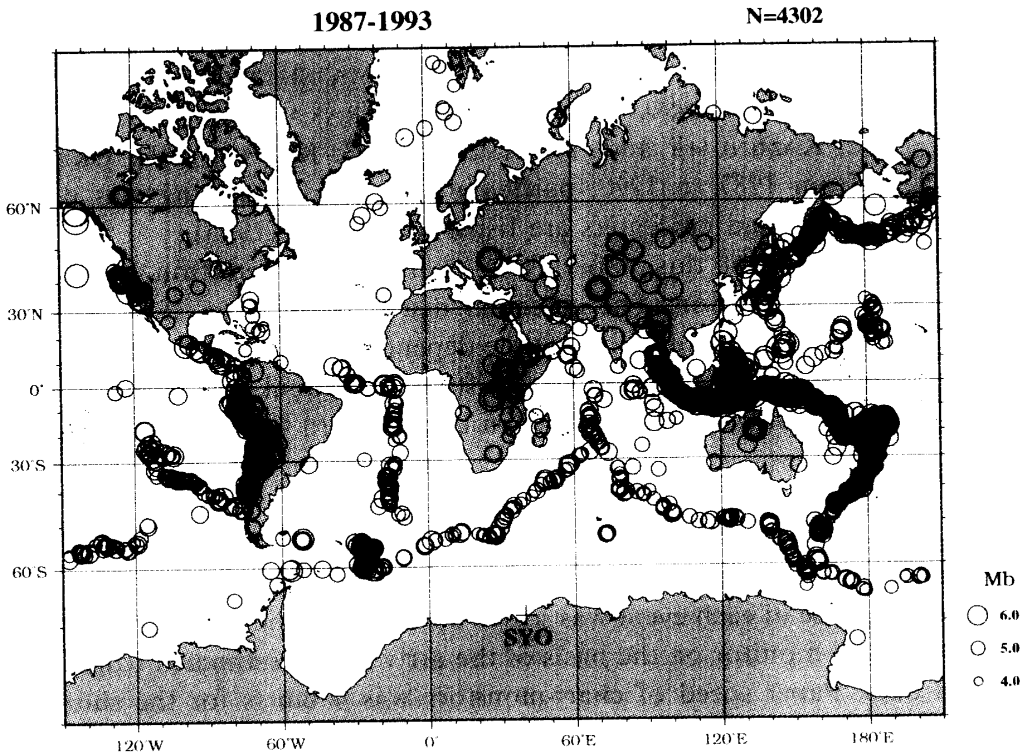


Fig. 1a. Epicentral distribution detected at Syowa Station for the seven year period from 1987 to 1993 by the Mercator projection. The total number of events (N) is 4302. The sizes of circles are proportional to the body-wave magnitude (Mb) determined by USGS.

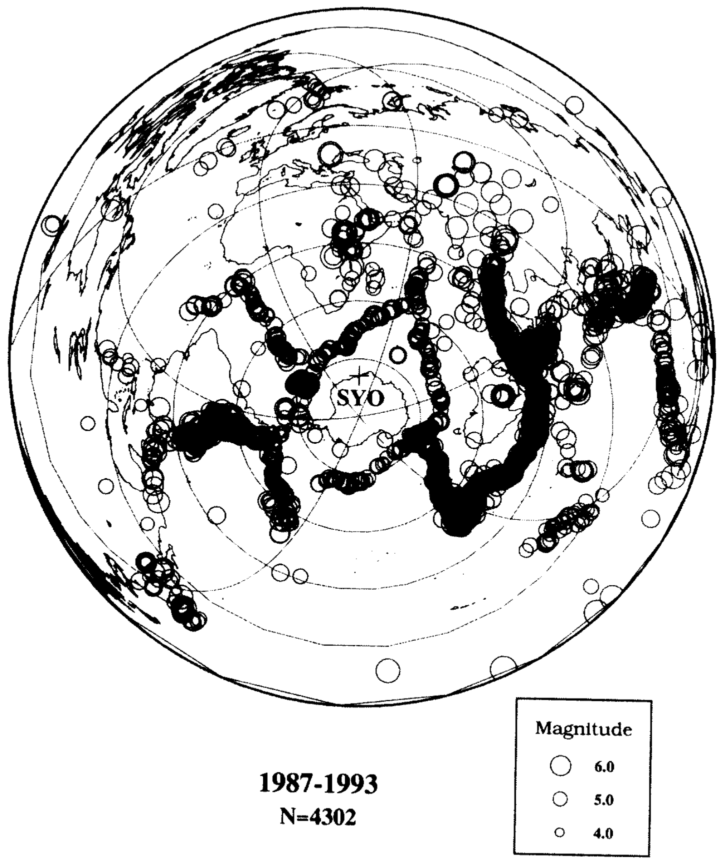


Fig. 1b. *Epicentral distribution from 1987 to 1993 by the Equi-azimuthual and equi-distant projection of its center at Syowa Station (SYO). The number of events (N) and the projection schemes are the same as in Fig. 1a.*

tional to the body-wave magnitude (Mb) by USGS.

3. Characteristics of Detected Epicenters

3.1. Spatial distributions

In this section, some relationships between epicental parameters were investigated in order to find the spatial distribution. Figure 2a shows the relationship between the epicentral distance and the focal depth for all 4302 events. The maximum number of events is located in the epicentral distance range from 70° to 100°. Since the epicentral distances from 100° to 140° are in the shadow zone for seismic body-waves, very few initial phases were detected. For distances over 140°, PKP phases are mainly observed as initial phases. Figure 2b shows the relationship between azimuth and focal depth. Earthquakes with focal depth deeper than 300 km are distributed mainly in the azimithual ranges of 70°-90° (Indonesia region), 130°-150° (Tonga and Fiji Island regions) and around 250° (South America), respectively. Figure 2c shows the relationship between azimuth and distance. The earthquake distribution pattern seems to correlate with the plate boundaries. The earthquakes in the distance range

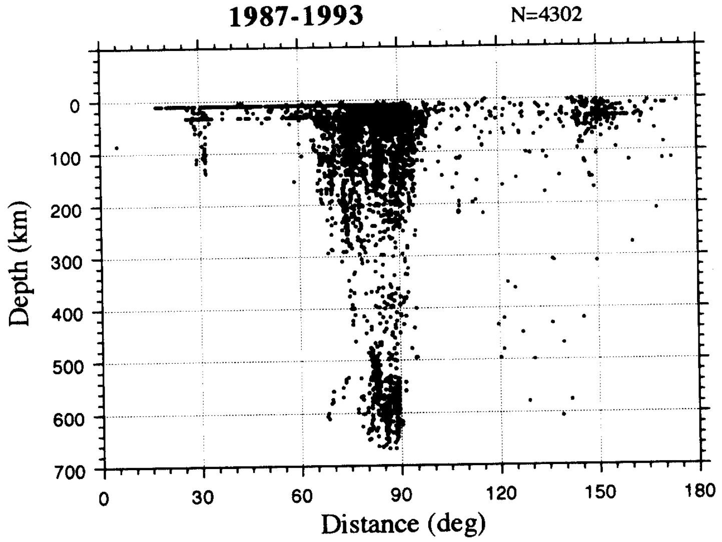


Fig. 2a. Relationship between the epicentral distance (deg) and the focal depth (km) for the aggregate of 4302 events. The maximum number of events is in the distance range from 70° to 100°. The seismic shadow zone is clearly indicated in the distance range from 100° to 140°. The PKP phases are identified in the distance range of more than 140°.

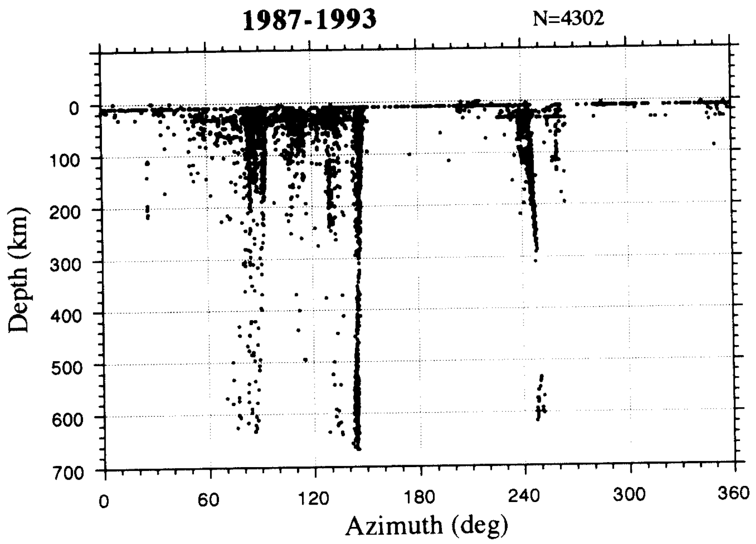


Fig. 2b. Relationship between the azimuth (deg) and the focal depth (km). Deep earthquakes more than 300 km deep are located mainly in the azimithual ranges of 70°- 90°, 130°- 150° and around 250°.

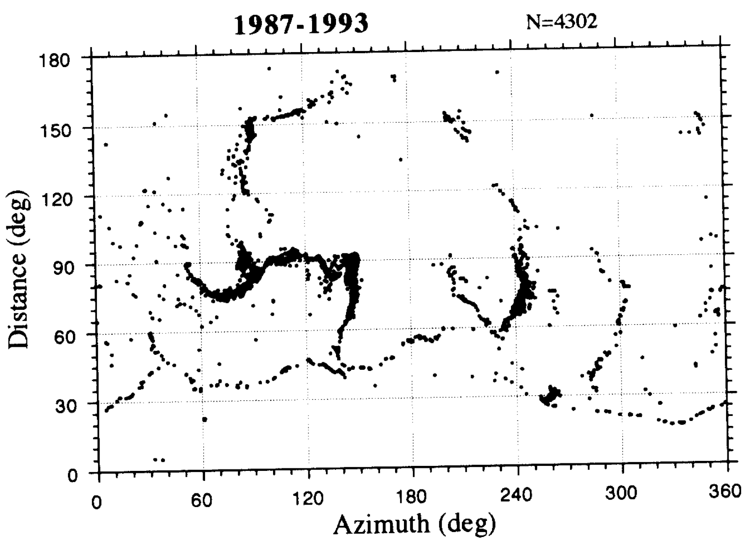


Fig. 2c. Azimuthal variation of epicenter against distance. Most earthquakes are located along plate boundaries. The detection capability is higher in the southern hemisphere than in the northern hemisphere.

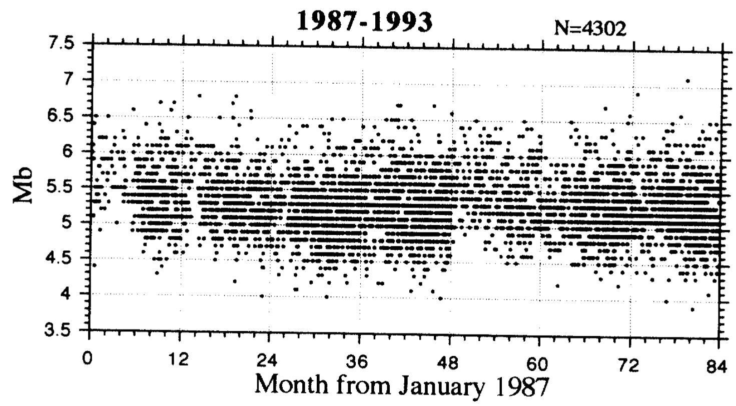
more than 150° are located in high northern latitude such as the region of Alaska, Aleutian Islands, Kamchatka Peninsula and Svalbard, etc.

3.2. Monthly change

In this section, time variations from 1987 to 1993 about some epicentral parameters are investigated. Figure 3a shows the time variations of body-wave magnitude (Mb) for the seven year period. The X-axis shows the number of months counted from January 1987. The maximum and the minimum detectable magnitude ranges are from 6.5 to 7.0, and 4.0 to 4.5, respectively. Variations of period longer than one year are not found. This indicates that the earthquake detection level was not so changed throughout these seven years. The austral summer, however, has less detectability than winter for all seven years, because of high noise level in the summer season caused by both oceanic effects and human activity within the station.

Time variations for the seven year period about the focal depth, epicentral distance and azimuth are presented in Figs. 3b–3d. No clear variations were found in

(a)



(b)

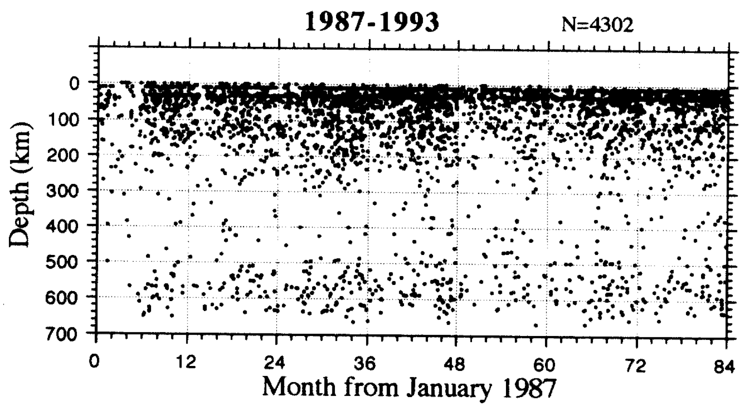
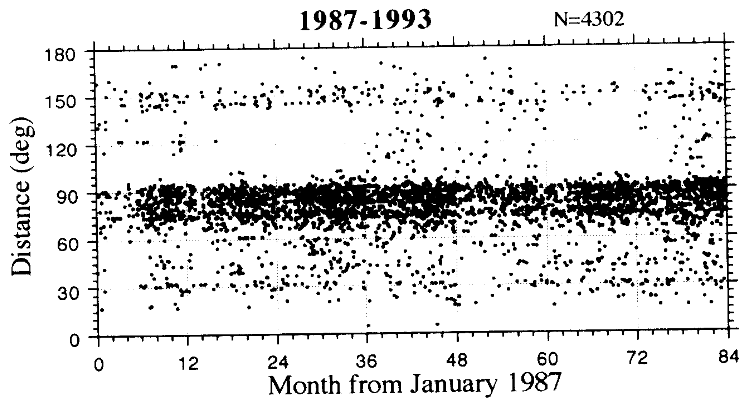


Fig. 3a. *Time variations of body-wave magnitude (Mb) for the seven-year period from 1987 to 1993. The minimum threshold of detectable magnitude ranges from 4.0 to 5.0. The unit of the holizontal axis is the number of months from January 1987.*

Fig. 3b. *Time variations of the focal depth (km) for the seven-year period from 1987 to 1993.*

(c)



(d)

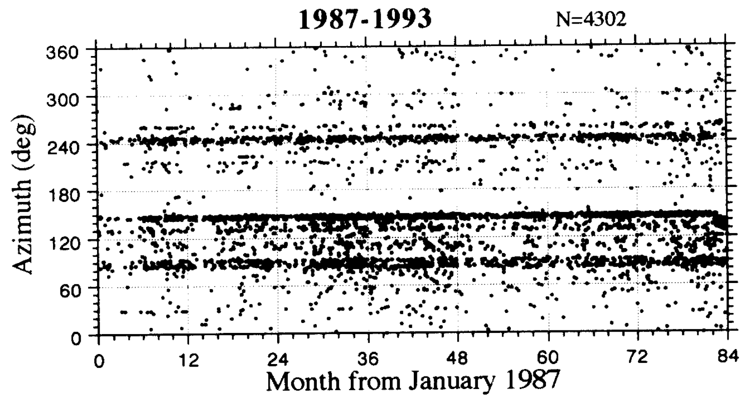


Fig. 3c. Time variations of the epicentral distance (deg) for the seven-year period from 1987 to 1993.

Fig. 3d. Time variations of the azimuth (deg) for the seven-year period from 1987 to 1993.

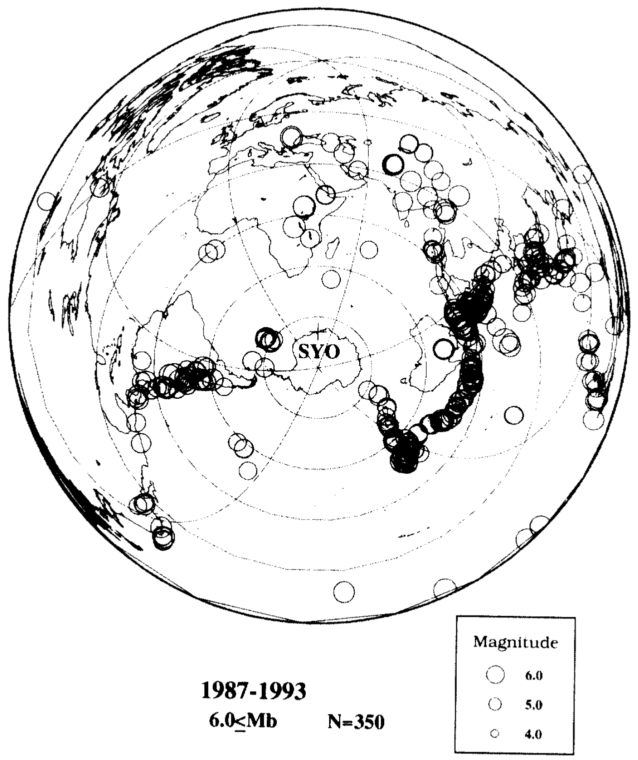
these epicental parameters in these seven years. The variation of epicentral distance shows little change in the shadow zone distance from 100° to 140°. These events seem to include explosion experiments in North America to produce the first arrival phases.

3.3. Magnitude dependency

In this section, the magnitude dependence is investigated in relation to the spatial distribution and the number of detected events for various magnitude ranges. Figures 4a–4d show the epicentral distribution for four degrees of body-wave magnitude (Mb) of (a) greater than 6.0, (b) from 5.5 to 6.0, (c) from 5.0 to 5.5, and (d) smaller than 5.0. The numbers of earthquakes in each group are 350, 1093, 1984 and 875, respectively. The larger the magnitude, the longer the maximum distance to the detected epicenters. Earthquakes smaller than 5.0 (d) are mainly deep events and events along the ridges around Antarctic plate.

The relationship between the epicental distance and body-wave magnitude for the 4302 events is shown in Fig. 5a. The lower limit of body-wave magnitude is about 4.0, in the range of epicental distance from 50° to 100°. There are 3527 events in this

(a)



(b)

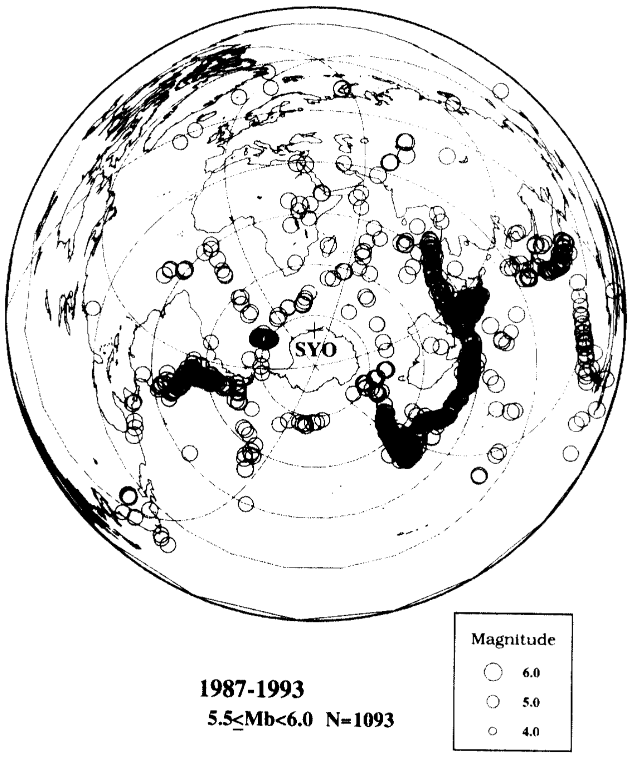
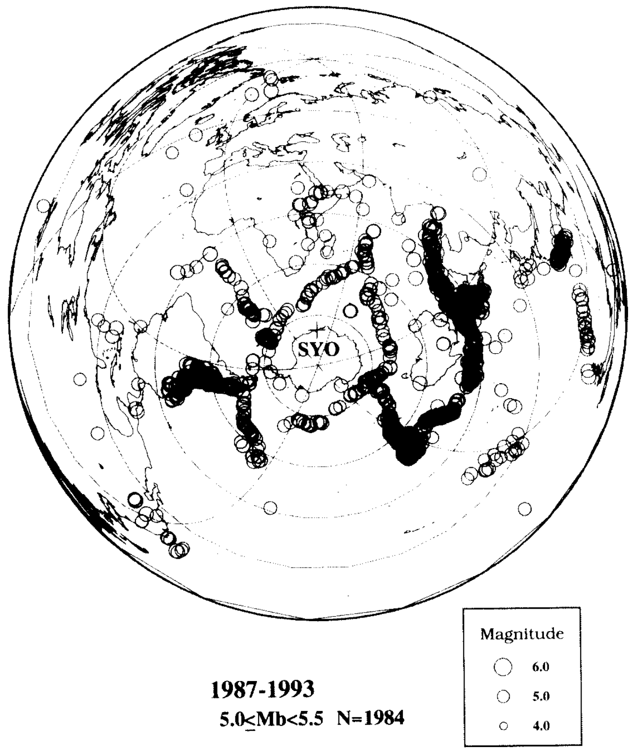


Fig. 4a. Epicentral distribution of detected earthquakes with body-wave magnitude (Mb) greater than 6.0 for the seven-year period on the Equi-azimuthual and equi-distant projection with its center at Syowa Station (SYO). The number of events in this magnitude range is 350.

Fig. 4b. The same epicental distribution as in Fig. 4a with magnitude ranging from 5.5 to 6.0 for the seven-year period. The number of events in this magnitude range is 1093.

(c)



(d)

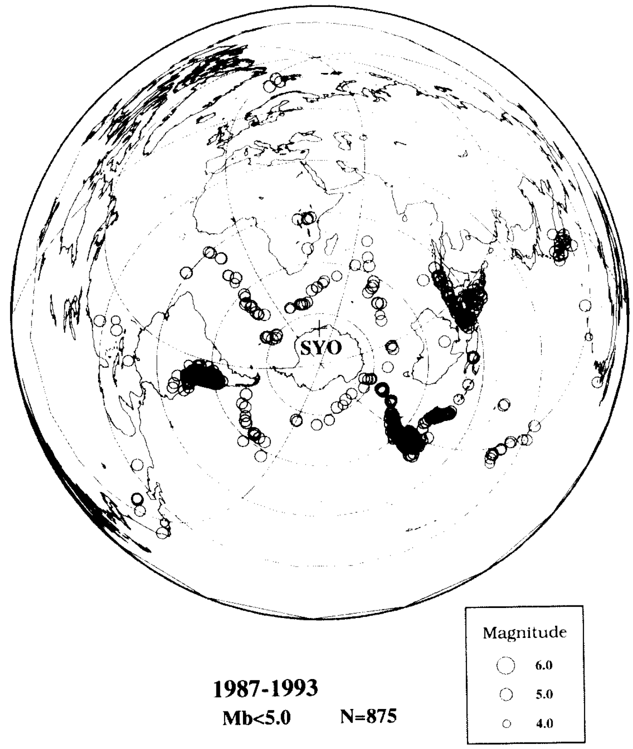


Fig. 4c. *The same epicental distribution as in Fig. 4a with magnitude ranging from 5.0 to 5.5 for the seven-year period. The number of events in this magnitude range is 1984.*

Fig. 4d. *The same epicental distribution as in Fig. 4a with magnitude smaller than 5.0 for the seven-year period. The number of events in this magnitude range is 875.*

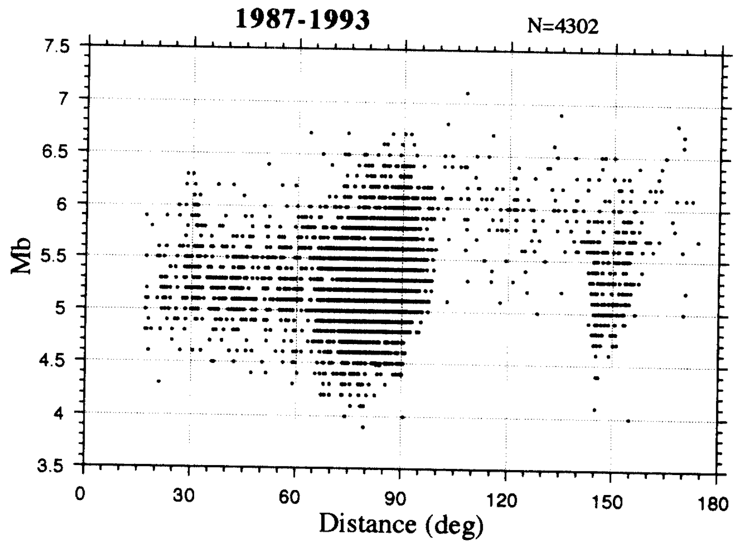


Fig. 5a. Relationship between the epicentral distance (deg) and body-wave magnitude (Mb) for the aggregate of 4302 events for the seven-year period of observation. The magnitude threshold has a minimum value about 4.0 corresponding to the maximum number of events from 70° to 100° and a maximum threshold range in the shadow zone from 100° to 140°.

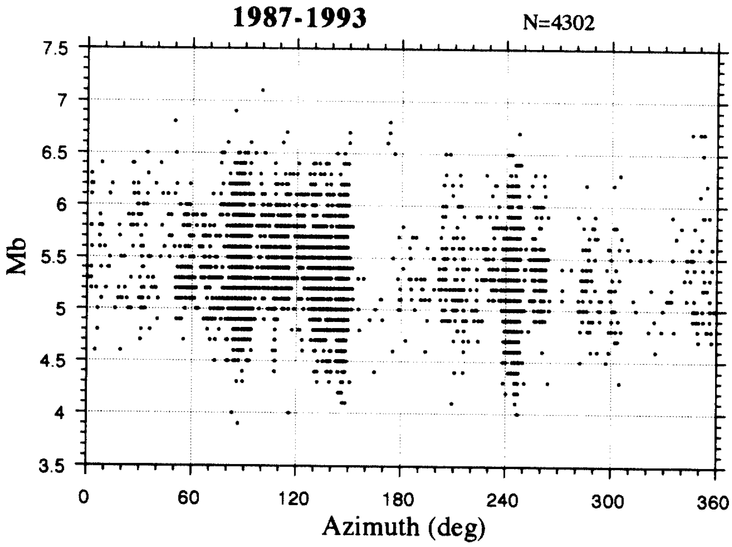


Fig. 5b. Relationship between the epicental azimuth (deg) and body-wave magnitude (Mb) for the aggregate of 4302 events. The magnitude threshold has minimum values around the azimuths of the locations of deep earthquakes.

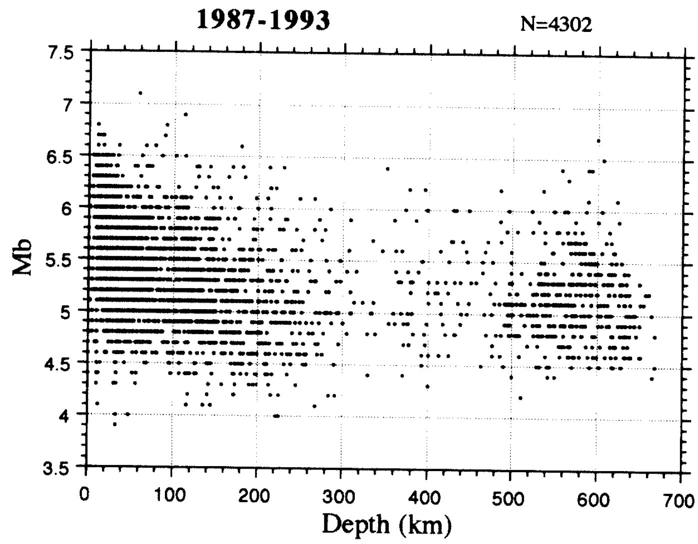


Fig. 5c. Relationship between the focal depth (km) and body-wave magnitude (Mb) for the aggregate of 4302 events. The magnitude threshold has minimum values in the shallow depth up to 300 km.

distance range, about 80 per cent of the total events. That is also about ten times the numbers in the distance ranges less than 50°, and 100° to 180°. The magnitude threshold has values about 5.0 in the shadow zone from 100° to 140°. The focal depths of the events with body-wave magnitude 4.0–4.5 are mostly found to exist between 100 and 200 km in the detailed investigation.

In the same way, the relationship between the azimuth and body-wave magnitude for the aggregate of 4302 events is shown in Fig. 5b. The magnitude threshold has the minimum range around the azimuths of deep earthquakes (see Fig. 2b). The relationship between the focal depth and body-wave magnitude for the aggregate of events is shown in Fig. 5c. The magnitude threshold has minimum values at shallow depth up to 300 km; earthquakes with the maximum magnitude were detected near the surface region.

4. Detection Capability

The earthquake detection capability at Syowa Station was already investigated during the observation in first seismographic room (KAMINUMA, 1968). It was 7 per cent in the winter season and 2 per cent in the summer season compared with the

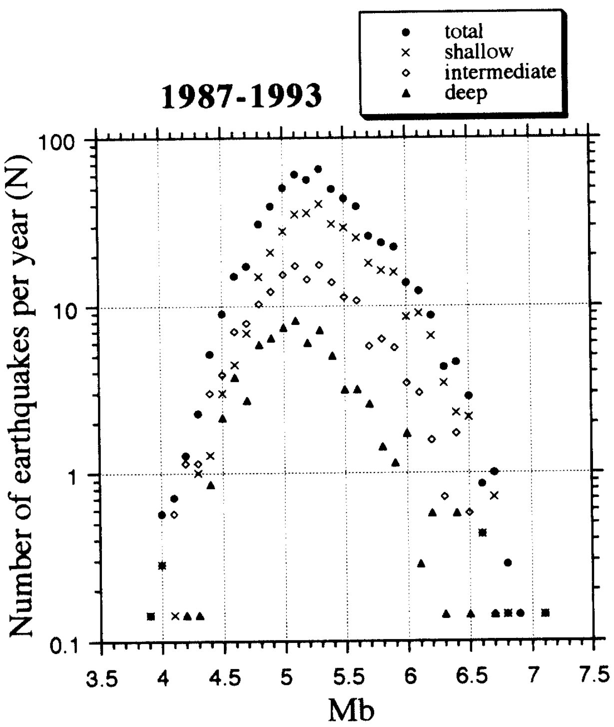


Fig. 6. Annual mean number of detected earthquakes (N) for the seven-year period from 1987 to 1993 against body-wave magnitude (Mb). The numbers of events for each group are marked with an increment of 0.1 Mb (solid circle, aggregate of 4302 events; crosses, shallow events of focal depth smaller than 50 km; open diamonds, intermediate events of focal depth from 50 km to 300 km; solid triangles, deep events of focal depth larger than 300 km).

number of detected teleseismic events reported by the USGS. The detectability in the new seismic vault was improved to 23 per cent, about three-times that of the previous seismographic room (KAMINUMA and CHIBA, 1973). The South Pole Station (SPA), however, has higher detection capability than other Antarctic stations, because SPA is located in the center of the continent, the most distant place from the ridges surrounding the Antarctic plate. Thus the seismic noise amplitudes caused by oceanic effects are presumably smaller than at other stations along the Antarctic coast.

Figure 6 shows the relationship between the annual mean number of detected events and body-wave magnitude (Mb) with an increment of 0.1 at Syowa Station. The numbers were divided into four groups such as (1) total events (solid circles), (2) shallow events of depth smaller than 50 km (crosses), (3) intermediate events 50–300 km deep (open diamonds), (4) deep events deeper than 300 km (solid triangles). The peak number of events against magnitude is around 5.3, where the number of earthquakes per year is about 70. All of the three depth ranges have the same peak position of magnitude around 5.3.

The detection capability of teleseismic events has been evaluated by the reports to ISC from 115 global seismic networks for the ten year period from 1971 to 1980 (RINGDAL, 1986). He also pointed out that the magnitude threshold of earthquake detection has a gradual increase with increasing southern latitude. The bias problem of network magnitude determination is significant at small and middle magnitudes, particularly at high southern latitude. The 90 per cent incremental body-wave magnitude threshold ranges from 4.2 to 4.8 in the southern hemisphere.

Although there are some broad-band seismic stations distributed in the southern hemisphere by the GEOSCOPE project (ROMANOWICZ *et al.*, 1991), the detection capability of earthquakes in the southern hemisphere should be improved by increasing the number of seismological stations, particularly in the Antarctic continent and the surrounding oceans. ROULAND *et al.* (1992) pointed out the existence of undetected earthquakes in ISC in the southern hemisphere by using broad-band GEOSCOPE data. Around Syowa Station, some local earthquakes with magnitude range smaller than 3.0 were actually detected by the tripatite seismic array in the Lützow-Holm Bay region from 1987 to 1990 (KAMINUMA and AKAMATSU, 1992). International cooperation in observations and data exchange should also be promoted in order to advance the seismological study in the southern hemisphere.

5. Publication of Epicentral Data

Syowa Station has an important role in distributing seismic data as one station of the Japanese Pacific Orient Seismic Digital Observation Network (POSEIDON) (TSUBOI, 1995). The hypocentral data for the seven year period covered in this analysis are available from the 'JARE Data Reports', and are also in the sub directory /pub/HYPO of Workstation (133.57.3.2) in the Earth Science Division of NIPR. An example of the data format is shown in Table 2. Anyone can obtain these data via the Internet by use of the 'ftp' command on the UNIX system as follows. See the 'README' file for the first trial.

Table 2. Example of the formatting of hypocentral parameters for the period of the first 10 data in January 1987. These hypocentral files are available using the 'ftp' command via the Internet by accessing the Earth Science Division, NIPR.

Year	Data Rep. No.	Origin Time M D h m s	Lat. deg	Lon. deg	Depth km	Mb	Distance deg	Azimuth deg
1987	1	01 02 07 42 43.7	−42.437	−18.428	10	5.1	39.711	281.134
1987	2	01 03 22 04 04.8	−14.998	167.929	15	6.0	88.638	130.718
1987	3	01 05 12 11 55.7	52.448	−169.381	33	6.1	158.612	125.913
1987	4	01 09 06 14 44.8	39.895	141.677	68	6.4	130.928	83.929
1987	5	01 09 08 01 35.9	−19.469	−176.538	33	5.9	88.010	146.198
1987	6	01 11 07 30 11.1	−18.815	−174.069	104	5.1	89.125	148.348
1987	7	01 13 10 55 17.9	−29.292	−177.524	60	5.3	78.263	147.452
1987	8	01 14 11 03 48.7	42.565	−142.850	102	6.5	133.699	175.963
1987	9	01 14 12 44 50.8	−32.624	−67.252	158	5.5	65.553	242.424
1987	10	01 16 15 14 59.3	−52.904	27.444	10	5.5	17.083	334.389

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ftp> open 133.57.3.2
Connected to 133.57.3.2.
220 geoipx FTP server (SunOS 4.1) ready.

Name (133.57.3.2:user): ftp or anonymous
Password:   (enter your e-mail address)
230 Guest login ok, access restrictions apply.

ftp> cd pub/HYPO
ftp> ls
     1987.syo
     1988.syo
     1989.syo
     1990.syo
     1991.syo
     1992.syo
     README
ftp> mget *.syo
ftp> bye
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The seismic observations at Syowa Station are organized by the authors and Prof. K. SHIBUYA of NIPR. Detailed information on seismic observations and the data service are available from them. Questions concerning seismic data should be directed to *kanao@nipr.ac.jp.*

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References

AKAMATSU, J. and KAMINUMA, K. (1989): Seismological bulletin of Syowa Station, Antarctica, 1989. JARE Data Rep., **145** (Seismology 22), 1-73.

ETO, T. (1962): On the electromagnetic seismographs at Syowa Base. Nankyoku Shiryô (Antarct. Rec.), **14**, 48-50.

KAMINUMA, K. (1968): Syowa Kiti no jishinkei-shitsu (Johô) (Earthquake detection capability of Syowa Station, Antarctica (preliminary reports)). Nankyoku Shiryô (Antarct. Rec.), **33**, 71-80.

KAMINUMA, K. and AKAMATSU, J. (1992): Intermittent micro-seismic activity in the vicinity of Syowa Station, East Antarctica. Recent Progress in Antarctic Earth Science, ed. by Y.Yoshida *et al*. Tokyo, Terra Sci. Publ., 493-497.

KAMINUMA, K. and CHIBA, H. (1973): Syowa Kiti no shin-jishinkei-shitsu to jishin kenchiritsu (The new seismographic vault and the detection capability of Syowa Station, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **46**, 67-82.

KAMINUMA, K. and ICHIKAWA, N. (1990): Seismological bulletin of Syowa Station, Antarctica, 1990. JARE Data Rep., **151** (Seismology 23), 1-78.

KAMINUMA, K. and MURAKAMI, H. (1991): Seismological bulletin of Syowa Station, Antarctica, 1989. JARE Data Rep., **160** (Seismology 24), 1-66.

KAMINUMA, K. and NAGASAKA, K. (1992): Seismological bulletin of Syowa Station, Antarctica, 1990. JARE Data Rep., **172** (Seismology 25), 1-106.

KAMINUMA, K. and YAMAMOTO, M. (1993): Seismological Bulletin of Syowa Station, Antarctica, 1991. JARE Data Rep., **185** (Seismology 26), 1-53.

KAMINUMA, K., ETO, T. and YOSHIDA, M. (1968): Syowa Kiti no jishin kansoku (Seismological observation at Syowa Station, Antarctica). Nankyoku Shiryô (Antarct. Rec.), **33**, 65-70.

KANAO, M. (1994): Seismological bulletin of Syowa Station, Antarctica, 1992. JARE Data Rep., **192** (Seismology 27), 1-69.

KANAO, M. (1995): Re-scaling of seismic events at Syowa Station, Antarctica, 1987-1990. JARE Data Rep., **200** (Seismology 28), 1-212.

KANAO, M. and KAMINUMA, K. (1993): Nankyoku Syowa Kiti ni okeru chôkôseinô jishinkei ni yoru kôtaiiki kôkando jishin kansoku — Dai-33-ji kansokutai hôkoku 1992 — (Broad-band and wide dynamic-range seismic observations with a Streckeisen seismometer (STS) at Syowa Station, East Antarctica — JARE-33 status report (1992) —). Nankyoku Shiryô (Antarct. Rec.), **37**, 291-318.

MURAKAMI, H. and KAMINUMA, K. (1991): Broad Band Seismic Observation by STS Seismometer at Syowa Station, Antarctica. Program and Abstructs, Seism. Soc. Jap., **1**, 62.

NAGASAKA, K., KAMINUMA, K. and SHIBUYA, K. (1992): Seismological observations by a three-component broadband digital seismograph at Syowa Station, Antarctica. Recent Progress in Antarctic Earth Science, ed. by Y. YOSHIDA *et al*. Tokyo, Terra Sci. Publ., 595-601.

OKANO, K. and KANAO, M. (1995): Seismological Bulletin of Syowa Station, Antarctica, 1993. JARE Data Rep., **207** (Seismology 29), 1-95.

RINGDAL, F. (1986): Study of magnitudes, seismicity and earthquake detectability using a global network. Bull. Seism. Soc. Am., **76**, 1641-1659.

ROMANOWICZ, B., KARCZEWSKI, J. F., CARA, M., BERNARD, P., BORSENBERGER, J., CANTIN, J. M., DOLE, B., FOUASSIER, D., KOENIG, J. K., MORAND, M., PILLET, R. and ROULAND, D. (1991): The Geoscope Program: Present Status and Perspectives. Bull. Seism. Soc. Am., **81**, 243-264.

ROULAND, D., CONDIS, C., PARMENTIER, C. and SOURIAU, A. (1992): Previously Undetected Earthquakes in the Southern Hemisphere Located Using Long-period Geoscope Data. Bull. Seism. Soc. Am., **82**, 2448-2463.

TSUBOI, S. (1995): POSEIDON. IRIS Newsletter, Arlington, Vol. XIV, **1**, 8-9.

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